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in cooperation with
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EVALUATION OF GULLY-CONTROL STRUCTURES IN SOUTHWESTERN WISCONSIN

by

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INTRODUCTION

The Soil Conservation Service, as a part of its research program of designing more effective structures used in soil-conservation and water-control practices, has made field studies in various locations. The study, reported herein, was undertaken in cooperation with the University of Wisconsin to learn the present condition of the numerous gully-control structures erected in southwestern Wisconsin during 1933-38. All structures built in Buffalo, Trempealeau, Grant, and La Crosse Counties and 11 box-inlet drop spillways in Richland County were included in this investigation.

The study was conducted during the period 1947-49 to determine how the gully-control structures had performed under prevailing maintenance conditions. Enough time had elapsed to permit an evaluation of these structures for adequacy of designs, construction methods, and maintenance. Causes for shortcomings or failures, where they have occurred, need to be known in order to provide guidance when new structures are planned for this and other areas having similar soils, topography, and climate. Other purposes were to make recommendations on repairs and maintenance needed to protect the structures and prolong their usefulness. The diversity of structural types in these counties, together with the presence of sizeable areas of the principal soil types representative of the unglaciated area of southwestern Wisconsin, made the area selected a particularly favorable one for this study.

PLAN OF STUDY AND PROCEDURE

It was originally intended to make a highly detailed examination of all the permanent gully-control structures that had been built in the study area which would provide complete data on hydraulic, topographic, design, construction, and performance factors. Lack of enough resources for conducting such a detailed survey within a reasonable time, however, made it necessary to greatly simplify and reduce the scope of investigation.

Four hundred structures, most of which had been in operation for a period of 15 years or more, providing a fair sampling of conditions in the area of study, were actually

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[1] The contents of this report have been reviewed by Professors A. J. Wojta and O. R. Zeasman of the Wisconsin Agricultural Experiment Station; Professor A. T. Lenz of the Hydraulics Department, University of Wisconsin; and by M. M. Culp, head, Engineering Standards Unit, and members of the Region 3 Engineering Division, Soil Conservation Service. Their constructive comments and suggestions are gratefully acknowledged.

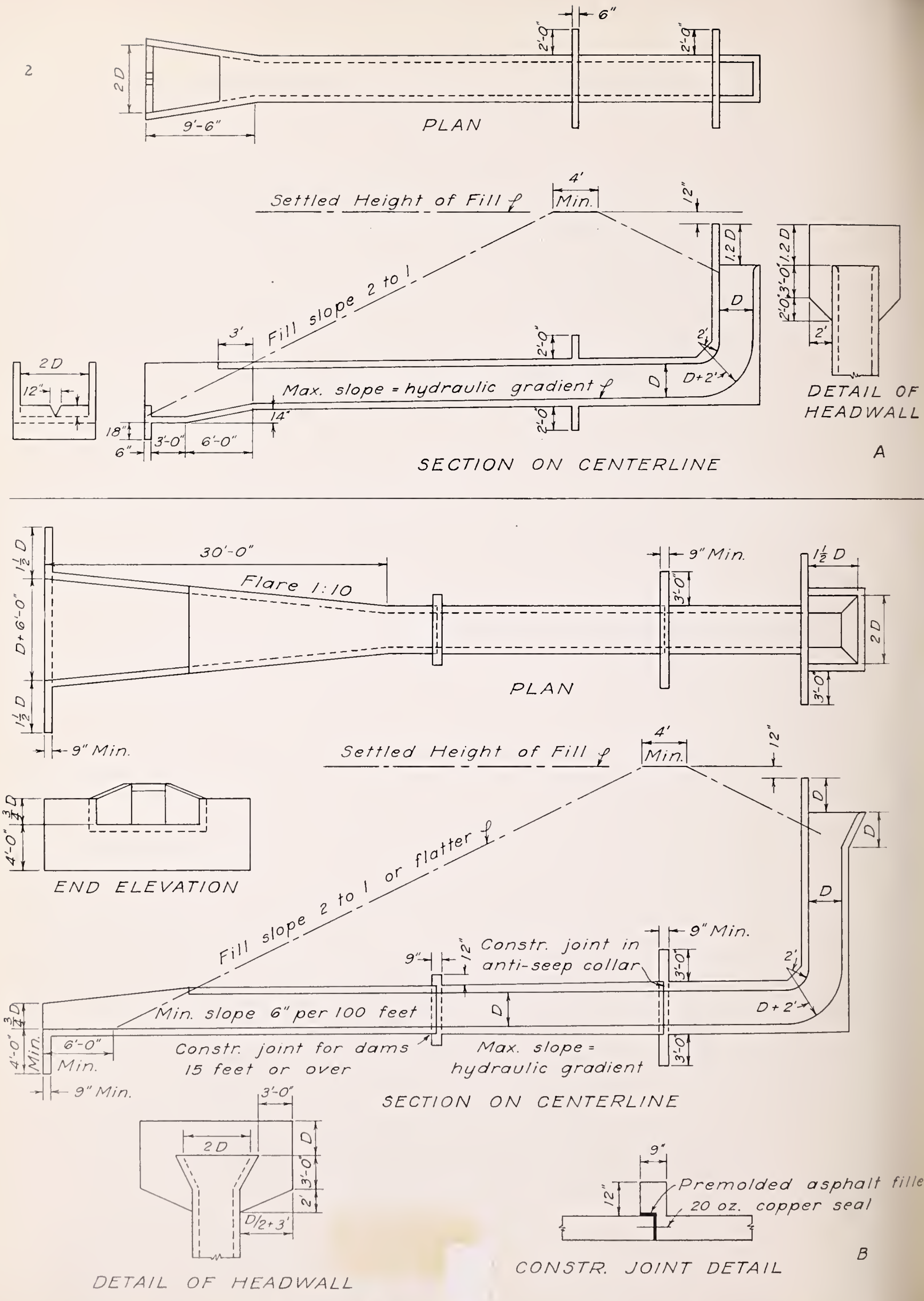

FIGURE 1.--Drop-inlet culverts: A, Type built in 1933; B, type constructed during 1934-38.

examined. Through use of a simple form of check sheet, data were obtained on the location, size, and type of structure; year of construction; size of drainage area; dates of maximum storms; runoff conditions and effect on structure; channel conditions; extent of scouring at structure outlet; and structural data. The general condition of each structure was noted, and where the structure had failed or was in need of repair or maintenance an attempt was made to determine the cause of failure and the nature and extent of the necessary remedial measures.

All available records bearing on the history of construction and previous repairs or maintenance were reviewed prior to examination of structures in the field. (With the exception of Buffalo and Trempealeau Counties, however, there was little information of a historical nature that could be used in the survey.) This was followed by a field inspection of each structure to determine its present condition, any defects which were evident, and the type of repair or maintenance required. The information was noted on the check sheet previously mentioned. Wherever possible the farmer was interviewed regarding previous repairs, performance of the structure, and the maximum flow through the structure. All structures were located on a United States Geological Survey map (1 inch to the mile if available).[2] Where possible the size of the drainage area above each structure was determined from aerial photographs having a scale of about 3 inches to the mile. The outline of the shape of the drainage area was drawn on the back of each check sheet. Photographs were later taken to illustrate specific conditions. Finally, the data were summarized by type of structure for each county.

CONDITION OF GULLY-CONTROL STRUCTURES AND ANALYSIS OF DATA

Drop-inlet Culverts

In all, 232 drop-inlet culverts were examined. One type of structure studied was the one most frequently constructed during 1933 (fig. 1, A), and the other was the common type built from 1934 to the end of the Civilian Conservation Corps construction period (fig. 1, B).

Failures were classified as complete or partial. Only 5 of the structures examined were considered to be complete failures (table 1). One failure resulted from overtopping during construction. Two occurred from overtopping during heavy floods after several years of satisfactory operation. One, occurring after 13 years of operation, was the result of settling of the riser caused by a soft foundation. The other failed 2 years after completion because of a porous sandfill. None of the complete failures resulted from undermining of the outlet.

The partial failures (table 1) included breaks in the fill, cracking off of the outlet or outlet wingwalls, cracking or tipping of the outlet flare walls, breaks at construction joints, and settling of the riser. Most of the fill failures occurred in the first 2 years after completion and were repaired immediately. Several of the early fill failures may be attributed to lack of antiseep collars and to use of earth for outside forms, thereby exposing the rough concrete surface (fig. 2). For reporting purposes, if the same fill failed more than once, each such failure and subsequent repair is considered as an independent occurrence.

In the table, a "repair" denotes replacement of the fill, addition of a drop outlet, rebuilding the outlet, completion of the riser and fill to the original height, or repairing a break in a construction joint. "Maintenance" denotes removal of weeds and brush, raising the fill to repair damage caused by cattle, and extending cutoffs which had been undermined. The total number requiring maintenance or repair exceeds the number listed separately at the top of the table as in need of repair or maintenance because several of the structures required more than one type of repair or maintenance.

Most of the drop-inlets examined in this study were constructed primarily for gully control and therefore designed to carry the runoff from the area undiminished by storage. The present trend is towards a greater use of this type of structure as outlets of large detention reservoirs intended mainly for reduction of flood peaks.

Inlet and riser conditions

Overtopping occurred on some of the low-head structures when, with the water level above the design head, the barrel did not flow at full capacity. The height of the riser was

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[2] A copy of the map and all check sheets for each county are on file in the Soil Conservation Service office in the respective county.

TABLE 1.--Drop-inlet structures. Census of structure condition, failures, and type of remedial treatment required

SITE AND STRUCTURE CONDITION

Description	County				Total
	Buffalo	Grant	La Crosse	Trempeleau	
	Number	*Number*	*Number*	*Number*	*Number*
Total examined	83	51	48	50	232
Complete failures	2	1	0	2	5
Partial failures	15	15	10	10	50
Structures needing repairs	5	5	4	4	18
Structures needing maintenance	36	13	20	13	82
Structures previously repaired	12	10	7	3	32
Cutoffs undermined	17	--	5	7	29
Cutting at the outlet	36	14	24	23	97
Deposition at the outlet	5	0	0	1	6
No flow through spillway	5	2	2	2	11
Large pond and minor flows	14	5	13	8	40
Condition satisfactory	40	32	25	26	123
REASON FOR FAILURES					
Outlet undermined	6	1	1	4	12
Insufficient cutoffs or collars	1	5	1	1	8
Use of earth for forms	--	5	--	--	5
Overtopping of fill	2	3	3	1	9
Inadequate structural design	3	1	3	1	8
Poor maintenance	1	--	--	--	1
Weak or wet foundation	1	1	1	3	6
Burrowing by animals or rodents	1	1	1	1	4
Seepage	2	--	--	2	4
Improper type or compaction of fill	2	7	3	2	14
Poor construction material	--	--	1	--	1
TYPE OF PARTIAL FAILURE					
Fill broken through	8	12	5	1	26
Cutoff undermined	8	1	--	4	13
Outlet cracked off	4	--	--	2	6
Wingwalls broken off	2	--	1	2	5
Settling of riser	1	1	1	3	6
Break in construction joint	2	--	--	3	5
Outlet flare walls cracked or tipped	5	1	7	5	18
MAINTENANCE OR REPAIR REQUIRED					
Replace fill	2	3	--	1	6
Raise fill to design height	8	2	5	1	16
Repair cattle damage	8	4	2	4	18
Clear brush and weeds	5	5	5	--	15
Clear brush around inlet	5	--	1	2	8
Add antiseep collars	--	2	--	--	2
Add drop or SAF outlet	2	--	--	3	5
Replace wingwalls	1	--	2	--	3
Extend cutoffs	14	2	4	7	27
Repair construction joints	6	1	1	3	11
Remove silt from above inlet or raise weir	1	--	1	--	2
Close portholes	2	1	1	3	7
Complete inlet and headwall	1	2	1	--	4
Clear silt and trees from outlet	8	2	2	--	12

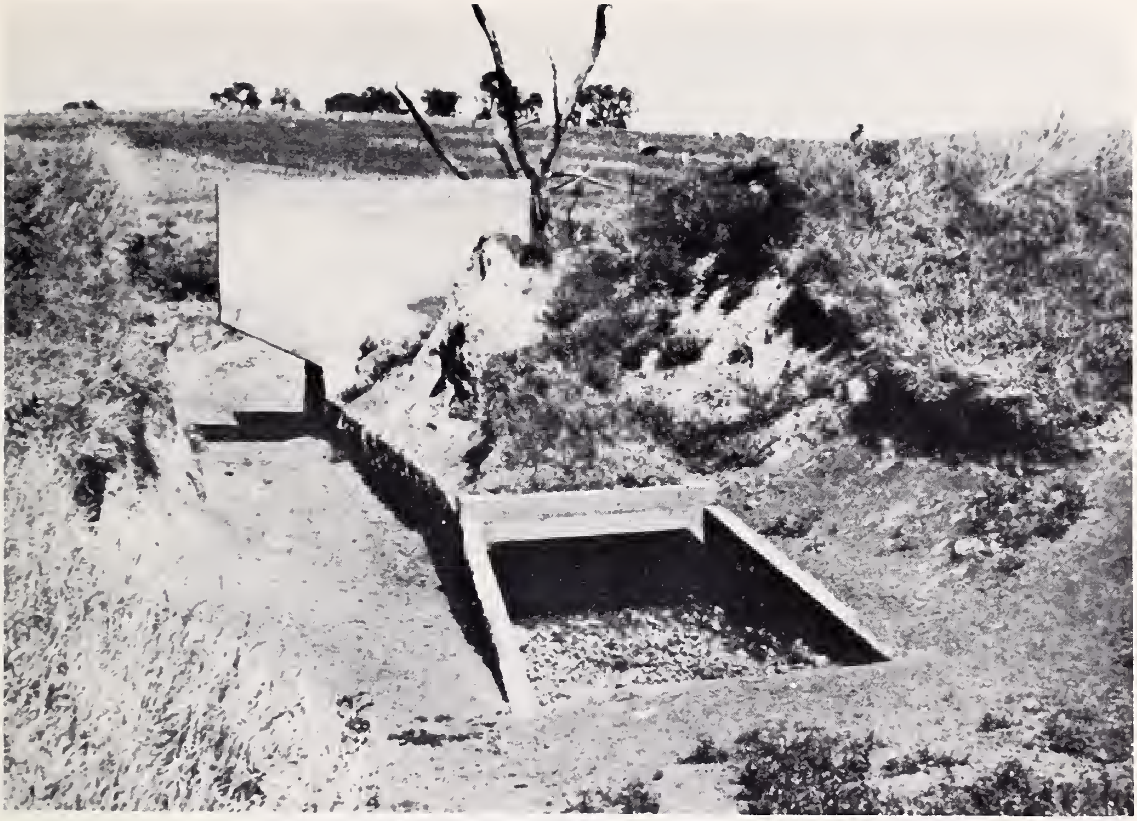

FIGURE 2.--Earth-fill failure on 5 x 5-foot drop-inlet structure, probably caused by lack of antiseep collar and use of earth for outside forms.

only one-half diameter above the top of the barrel. Flaring of the inlet on two or three sides or making the cross-sectional area of the riser at least twice that of the culvert may have enabled the structure to carry full capacity. Under heads of 10 feet or less the box-inlet drop spillway is a more practical structure.

The hydraulic characteristics are fairly well established for the straight inlet and for inlets having three sides flared in the upper one diameter. No data are available, however, on the type now being built where the width is the same as that of the conduit and the upstream end is flared from the top of the elbow on a slope not to exceed 1 to 5. This design is perhaps an improvement over either the original straight or flared inlet, but it would be desirable to know the hydraulic characteristics, especially in the case of twin structures. An undesirable feature of these larger risers is the danger of the inlet admitting debris too large to pass through the barrel although the enlarged elbow might tend to relieve this condition. Three cases of the riser and elbow being partly plugged with stumps were observed. These obstructions are difficult to remove. This hazard can be eliminated on new construction of detention reservoirs by providing trash racks to capture debris for later removal. The best method of protecting against this hazard on present structures or new ones with little temporary storage is to remove all large debris from the drainageways above the structure.

A few of the risers had opened up along the downstream side of a construction joint and in one case a small amount of earth fill had been drawn through this break. This condition generally appeared to have been caused by unequal earth pressures, but in two instances it was probably due to heaving of ice under the flared inlet. Indications were that the amount of steel used in the structures was not enough to carry the pressures involved.

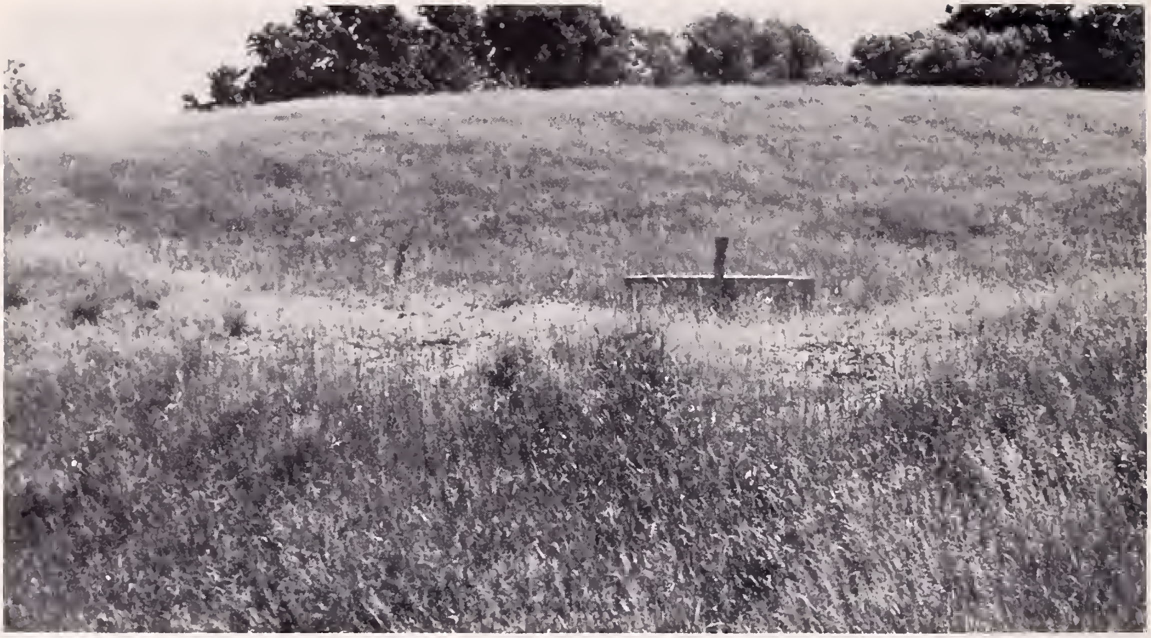

FIGURE 3.--Sag in fill caused by cattle damage reduced the effective capacity of the drop-inlet structure in this gully. View looking upstream.

FIGURE 4.--Lack of maintenance allowed brush and weeds to cover the fill and borders of the inlet of this twin 5 x 5-foot drop-inlet in Buffalo County.

Fill conditions

Many of the early failures were caused by improper compaction of the fill as the result of low-moisture content or poor gradation of the fill material. Many of the fills were in need of some kind of maintenance (table 1). Cattle had trampled several of them until the present head over the inlet was less than two-thirds of that originally planned (fig. 3). A number of the others had a rank growth of brush or weeds which encouraged the burrowing of rodents and other animals (fig. 4). One fill had been leveled and the soil had been spread out to make a roadway over the top. This reduced the freeboard above the inlet of the structure at least one-third. Most of the fills had top widths of 4 feet and 2 to 1 side slopes. Flatter slopes and wider top widths would have been easier to maintain. Periodic inspection and continuous maintenance of earth fills are essential.

Foundation conditions

Settling of the riser had occurred in 6 structures, and in all of these the construction joint under the center of the fill had broken open at the top. In one instance this resulted in complete failure. These 6 cases constitute less than 3 percent of the structures examined, but they point to a possible weakness in design. Considering the riser and that part of the barrel to the first construction joint below the elbow as a unit, the foundation pressure under this section will vary from a maximum at the upstream edge of the riser base to a minimum at the construction joint. The shorter the distance from the riser to the first construction joint, the greater will be the difference in foundation pressures. For fills over 15 feet high, for larger structures, or for structures with soft foundations, provision should be made for this difference in foundation pressures either in the form of a spread footing directly under the riser or by increasing the length of the first horizontal section.

One structure, the barrel of which had been placed on a limestone rock foundation, failed because the antiseep collar had been located directly over a hidden soft seam in the rock and had been keyed into the rock only a few inches. This seam, which extended diagonally under the barrel, washed out under the increased hydrostatic pressure and caused fill failure. Although this was an exceptional type of failure, it could have been prevented by drilling a few test holes in the rock foundation at the location of the antiseep collar to determine the presence of any planes of weakness.

Outlet conditions

At 181 sites, 78 percent of those examined, conditions were suitable for a study of erosion damage and structural defects at structure outlets. At the remaining sites, available pondage behind the structure was so great in comparison with the size of the drainage area that either no water had ever passed through the spillway (11 structures) or volume of discharge was negligible (40 structures). Of the structures providing significant information, 18 were the twin-culvert type ranging in size from 4 x 4 feet to 6 x 6 feet. Three of these had very large ponds that had carried only minor flows and one was on a sandstone foundation. All but 2 of the remaining 14 showed moderate to serious erosion at the outlet. In 4 of the 14, undermining of the cutoff and whirls around the wingwalls had caused these walls or the outlet to crack off.

The outlet on a twin 6 x 6-foot drop-inlet structure failed after the flood of August 3, 1937 (fig. 5). The peak flow of this flood, as estimated from high watermarks, was about 850 cubic feet per second. The original channel gradient downstream from this structure was 1 percent which seemed quite steep on a drainage area of about 1,500 acres. This structure was repaired by constructing a 5-foot drop-outlet to replace the outlet and by installing pile wings to reduce the erosion caused by swirls around the wingwall. It has operated very satisfactorily ever since. The outlet of a twin 5 x 5-foot drop-inlet structure was undermined and settled about 4 feet during two 1947 floods, each having a discharge of about 750 cubic feet per second (fig. 6). There were no cracks in the sidewalls, and the entire outlet end settled as a unit by breaking off at the first construction joint some 40 feet upstream from the lower end. This structure carried two equally heavy floods in 1949 with no apparent additional damage to either the outlet or fill. The maximum depth of the scour hole--7-1/2 feet--was about the proper floor depth for structures of this type designed in accordance with "St. Anthony Falls" outlet design criteria.

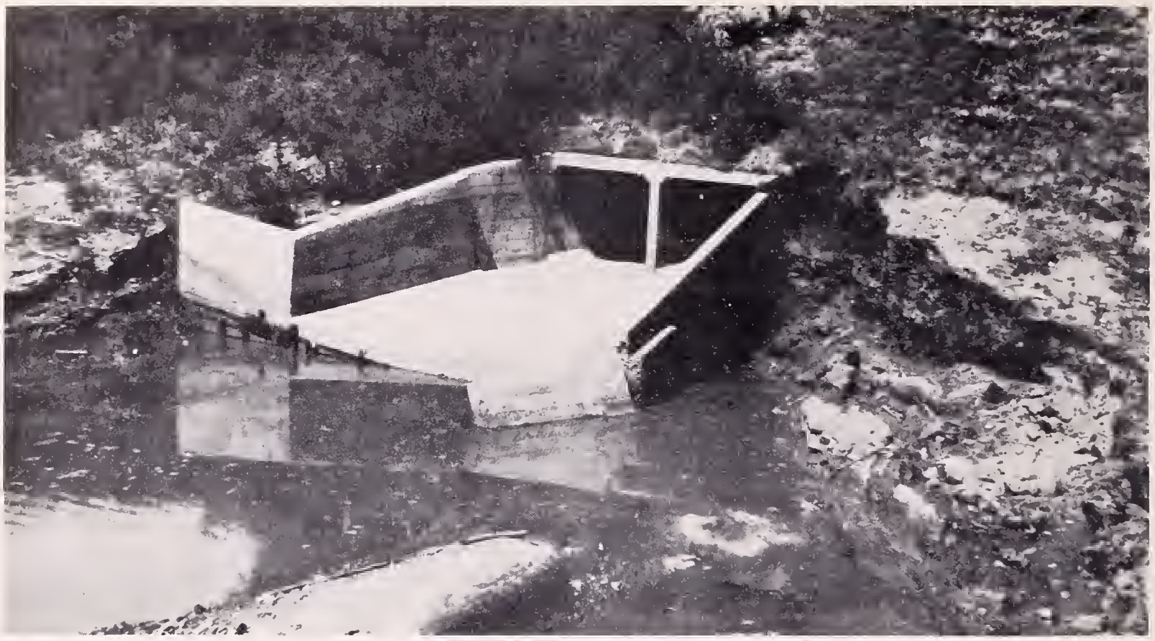

FIGURE 5.--Outlet failure of twin 6 x 6-foot drop-inlet structure caused by undermining as a result of an approximate peak discharge of 800 cubic feet per second on August 3, 1937. Original downstream gradient 1 percent.

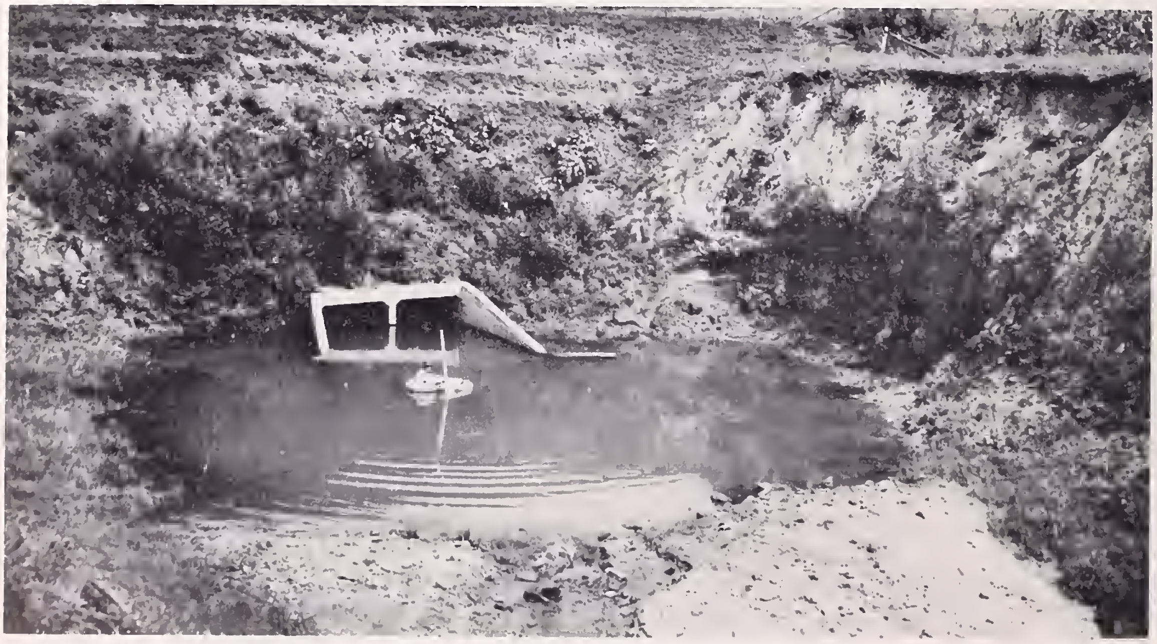

FIGURE 6.--Failure of outlet on twin 5 x 5-foot drop-inlet showing conditions after several peak flows of 750 to 850 cubic feet per second over a 3-year period. Maximum depth of scour hole 7½ feet.

About 50 percent of the single-barrel drop-inlets that were functioning under normal conditions showed some degree of cutting at the outlet, and in 1 out of 6 cases the cutoff had been undermined. No special provisions had been made in the design to control erosion at the outlets. Erosion below the outlet developed on a single-culvert 5 x 5-foot structure (fig. 7). The single instance of toe-wall undermining in Grant County, as contrasted with a higher percentage in all other counties, reflect the effect of type of bed material. Sandy soils apparently were the more erodible. Erosion at the outlet or undermining of the cutoff does not necessarily impair the effectiveness of the structure. Actually, many of the holes below these structures were formed within a few years after completion of the structure and have remained essentially the same up to the present time even though some of the worst floods have occurred in recent years.

The results of the field examination of these structures form the basis for certain recommendations with respect to improved design and immediate remedial action needed to correct existing structural failures.

Cutting at the outlet, for example, is rapid until the pond has completely silted. After that the downstream channel tends to build up. Unless the flow through the structure is greatly reduced, it is reasonable to expect some lowering of the downstream gradient even with a specially designed outlet.

Construction of a special outlet generally involves considerable excavation which in many cases may extend below ground-water level. A special outlet is justified only for structures larger than 4 feet in diameter built on sand or other extremely erodible soil, or for detention-reservoir installations where the maximum discharge must be carried for several hours at a time. A reasonably satisfactory remedy within the limits of the farmer's financial ability is to install a propped outlet or to merely set the cutoff back from the end of the apron, thus allowing a natural stilling basin to be cut without danger of undermining the cutoff. The propped outlet has been used satisfactorily with a number of small drop-inlet structures in recent years.

For structures larger than 4 x 4 feet, the outlet should be designed to conform with the SAF design criteria or the depth of toe-wall should be increased 6 to 8 feet and pile wings added on each side of the outlet to reduce erosion around the end of the wingwalls. Pile wings (fig. 8) have given satisfactory operation for several years although their useful life probably will not exceed 20 years.

In several structures the outlet flare walls had cracked off and tipped in at the top from 1 to 6 inches. This condition is partly attributable to poor design, partly to backfilling to the top of the wall during construction. As these walls are not intended to withstand pressure, the earth fill tends to cause collapse. In some structures considerable seepage of water at the toe of the fill back of these walls greatly increased the pressure.

Box-Inlet Drop Spillway

The two principal types of box-inlet drop spillway structures examined in southwestern Wisconsin were type-A, built in 1933, and type-B, generally used in later installations (fig. 9). Table 2 summarizes by counties the total number of structures examined; the number, type, and reason for failures; and the type of maintenance and repair required. Most of these structures were on large drainage areas and were designed for heads of 10 feet or less. Of the 52 examined, 5 were complete failures. One floated because no provision was made for uplift, 2 failed by piping through weep holes and undermining of the inlet section, and the other 2 ceased to function because of insufficient or poorly placed collars and cutoffs.

For the purposes of this report, "partial failures" include breaks through the fill (most of which had been repaired), breaking off of the downstream wingwalls, undermining of the cutoff, and diagonal cracking of the outlet sidewalls. "Repairs" include replacement of the fill, grouting under the floor, addition of a drop outlet, or rebuilding of wingwalls. "Maintenance" in general includes such minor work as repairing damage caused by cattle to the earth fill, removing brush and weeds from the immediate area, or extending the cutoffs.

One structure in every three had a partial failure at some time during the period, and more than half of these failures were due to total lack, insufficient number, or improper location of collars or cutoffs. Most of the structures had little or no storage basins above them and had to carry the full unregulated flow from the drainage area.

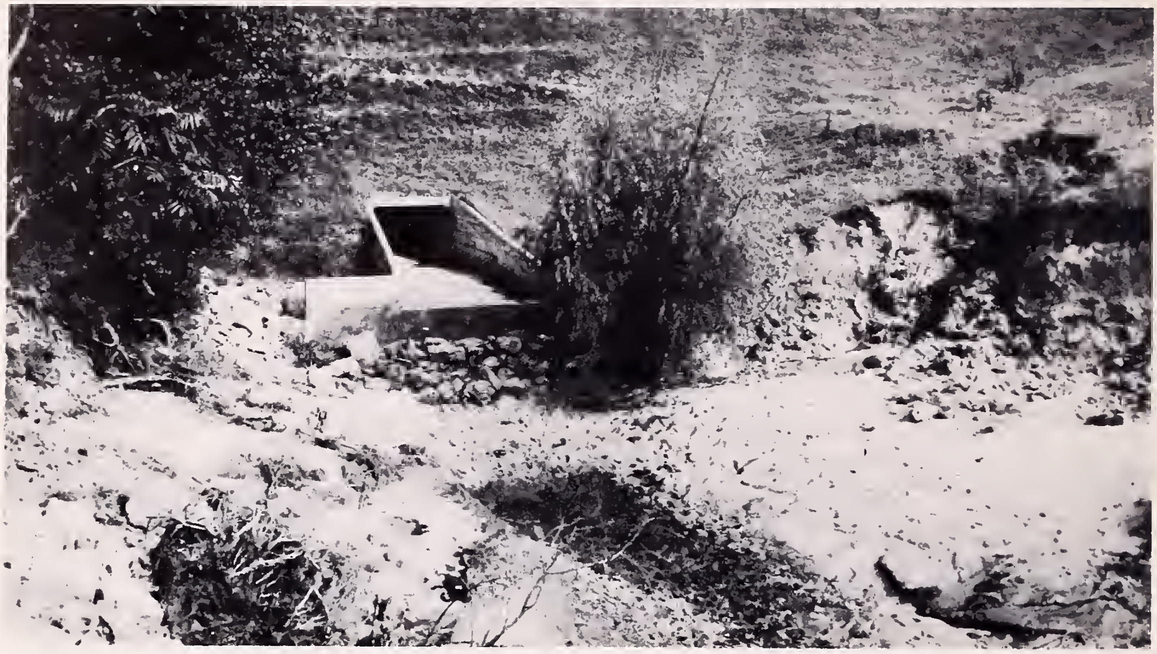

FIGURE 7.--Outlet erosion below 5 x 5-foot drop-inlet on sand after the flood of July 27, 1949, with an estimated peak discharge of 350 cubic feet per second. The large boulders against toe-wall were placed prior to this flood. Although the structure did not fail, frequent maintenance will be required.

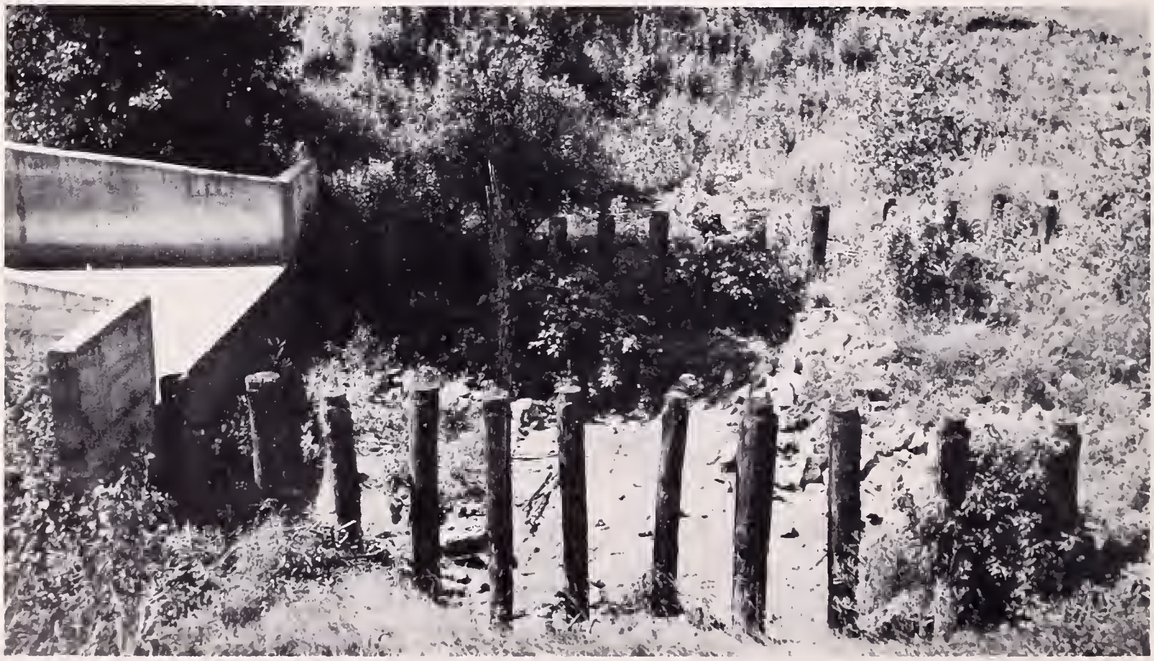

FIGURE 8.--Pile wings below twin 5 x 5-foot outlet to reduce erosion caused by whirls and back eddies around the wing-walls.

TABLE 2.--Box-inlet drop spillway. Census of structure condition, failures, and type of remedial treatment required.

SITE AND STRUCTURE CONDITION

Description	County					Total
	Buffalo	Grant	La Crosse	Richland	Trempeleau	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Total structures examined.........	8	7	8	11	18	52
Complete failures.................	1	--	1	2	1	5
Partial failures..................	1	2	1	8	8	20
Structures needing repairs........	1	1	--	1	6	9
Structures needing maintenance....	4	2	3	2	6	17
Structures previously repaired....	1	--	1	7	3	12
Cutoffs undermined................	--	--	1	1	3	5
Cutting at the outlet.............	2	2	2	4	6	16
Deposition at the outlet..........	--	--	2	--	2	4
Condition satisfactory............	3	3	4	2	6	18
REASON FOR FAILURES						
Outlet undermined.................	--	--	1	--	2	3
Combined headwall and cutoff......	--	--	--	6	2	8
Use of earth for forms............	--	--	--	2	--	2
Floated (no uplift figured).......	--	--	1	--	1	2
Poor structural design............	1	1	--	1	2	5
Piping through weep holes.........	1	--	--	3	--	4
Improper compaction of fill.......	--	1	--	--	1	2
Swirls aroung wingwalls...........	1	1	1	--	2	5
TYPE OF PARTIAL FAILURES						
Fill broken through...............	--	1	--	7	3	11
Cutoff undermined.................	--	--	1	--	2	3
Floating of inlet section.........	--	--	1	--	1	2
Wingwalls broken off..............	1	--	--	--	5	6
Inlet and channel undermined......	--	--	--	--	--	--
Outlet flare walls cracked........	--	1	--	1	3	5
MAINTENANCE OR REPAIR REQUIRED						
Replace fill......................	--	1	--	2	1	4
Raise fill to design height.......	--	2	--	--	1	3
Repair cattle damage..............	2	--	2	1	3	8
Clear brush and weeds.............	--	1	1	--	--	2
Clear brush around inlet..........	2	--	--	1	--	3
Extend antiseep collars...........	--	--	--	2	1	3
Add drop outlet...................	--	--	1	--	1	2
Replace wingwalls.................	1	--	--	--	5	6
Repair construction joints........	1	--	--	--	--	1
Remove silt from above inlet or raise weir..............	--	--	1	1	--	2
Remove silt from outlet and excavate channel...............	--	--	--	--	1	1
Extend cutoff walls...............	--	--	--	--	1	1

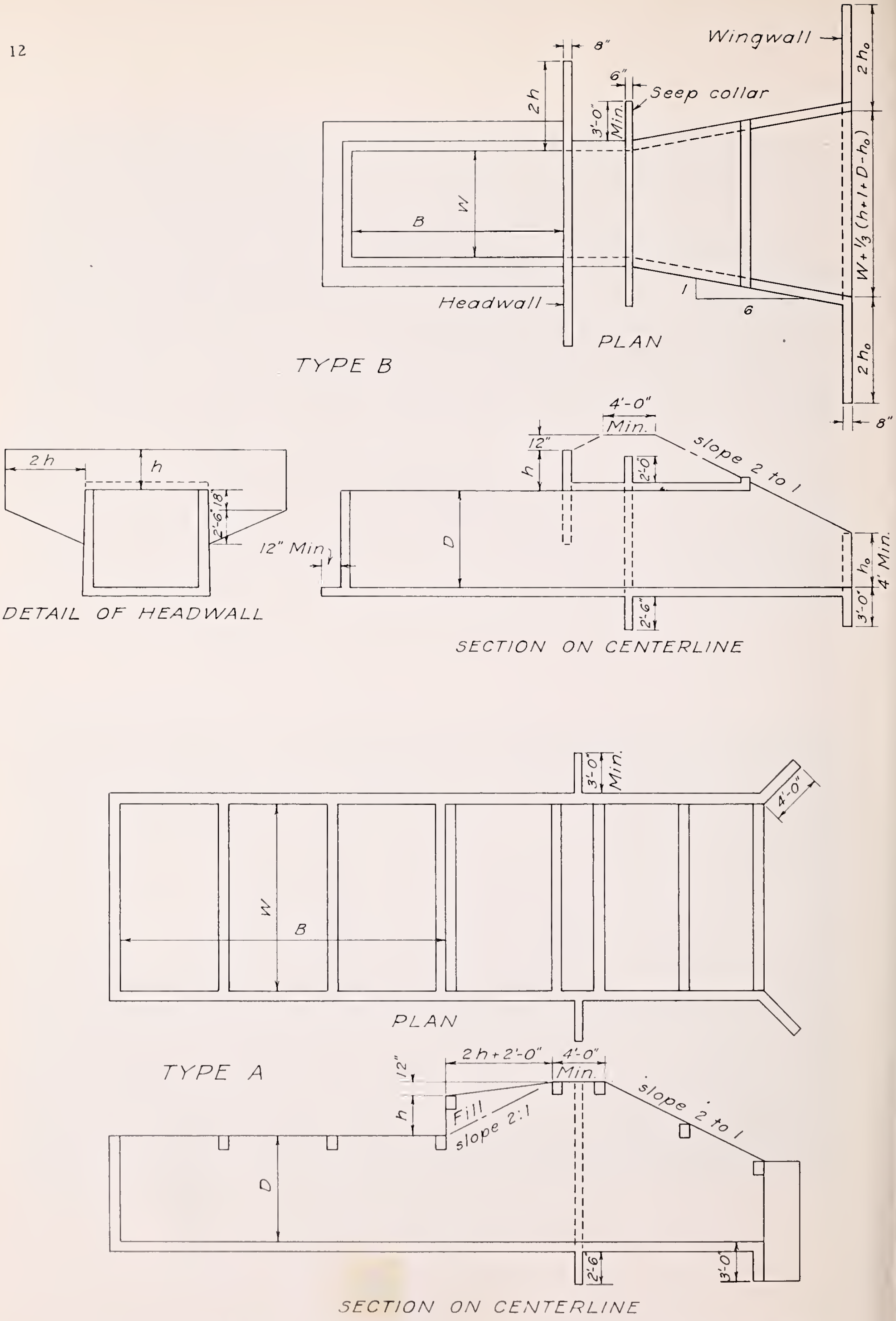

FIGURE 9.--Box-inlet drop spillways: A, Type built in 1933; B, type built from 1934-38.

Design weaknesses

Among several weaknesses apparent in the design of this type of structure, the most serious consisted of combining the only cutoff or antiseep collar with the headwall that divides the intake and channel sections (fig. 10). More than half of the box-inlet drop spillway structures constructed in this manner had one or more fill failures. Those having an independent antiseep collar under the center of the fill rarely had such failures. Present designs for this type of structure still combine the headwall and antiseep collar, but the length of the headwall has been measurably increased. Furthermore, in construction, much more care is exercised in the placement of the fill.

With combined headwall and antiseep collar, there was a decided tendency to crowd the toe of the fill against the spillway crest, thus seriously reducing the capacity, even though plans showed that the toe of the fill should be back a distance equal to the head on the crest of the spillway. With this type of design, the headwall should extend a minimum distance on each side of the inlet equal to three times the head on the crest plus 3 feet. Placing a short antiseep collar under the center of the fill and extending the sidewalls up along the fill slope will reduce the required concrete quantity by 10 percent. Tests to determine the hydraulic capacity of this type structure have recently been completed.[3]

In most of the early designs for the closed-top spillway and for spillways with a roadway over the fill, the closed section was considered as a rigid frame and the downstream wingwalls as simple cantilever beams. Adequate provision was not made for the transfer of stress between these two sections. For structures in excess of about 8 feet in depth this resulted in diagonal cracks in the outlet sidewalls and in cracks at the junction of these walls with the downstream end of the closed section. In some cases the sidewalls had tipped in over 1 inch at the top and the cracks had extended down at an angle more than 2 feet (fig. 11). This is a type of partial failure which probably may never develop into a complete failure. Designing the entire structure as a unit in accordance with modern design standards helps to eliminate this defect.

In many of the structures with closed-top spillways the roadway slab had been placed with the bottom surface level with the height of the spillway crest (fig. 10). Where silting occurred in the outlet, the capacity of the structure was seriously reduced by this design. Where it is necessary to place a roadway over the structure, the bottom of this slab should be at the maximum design headwater elevation.

A defect in early designs which led to the ultimate failure of some intakes was a provision for weep holes of tile encased in gravel pockets or porous concrete installed in the base of the intake section to relieve uplift pressure. Material was drawn up through these weep holes, undermining the intake section and making it necessary to replace this material and fill these weep holes with grout. These weep holes were eliminated in subsequent designs, and provisions were made for carrying the uplift loads by means of spread footings. Another remedy for this condition, which needs further testing before it can be generally recommended, consists of placing a gravel-encased tile drain around the intake section and outletting the drain through the sidewalls of this section.

Inlet conditions

The hydraulic capacity of box-inlet spillways up to sizes with a depth of 10 feet, width of 40 feet, and length of 80 feet has been given in a previous publication.[4] Usually this type of structure will probably be much smaller than these dimensions. In fact, intake sections as large as that mentioned above would mean a waste of material since the upstream end would not be used to its best efficiency hydraulically. The same weir length could be obtained by using a trapezoidal section with a width at the upstream end equal to $2\frac{1}{2}$ times the head on the crest, a sidewall length of 95 feet, and a width at the headwall of 40 feet. For this type of intake section, the uplift would be reduced by one-third and the base area of the section by about 800 square feet or 25 percent.

If very large structures of this type are to be built, the economy of using trapezoidal-inlet sections should be carefully considered. A straight section immediately below the headwall would not be required with this type of inlet since in most cases the alinement of the outlet sidewalls could be a continuation of that of the inlet-section sidewalls. Figure

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[3] Thesis, University of Wisconsin, Civil Engineering, 1953.

[4] Huff, A. N. The hydraulic design of rectangular spillways. U. S. Dept. Agr. Soil Conser. Serv., SCS-TP-71, 66 pp., illus. 1944. [Processed.]

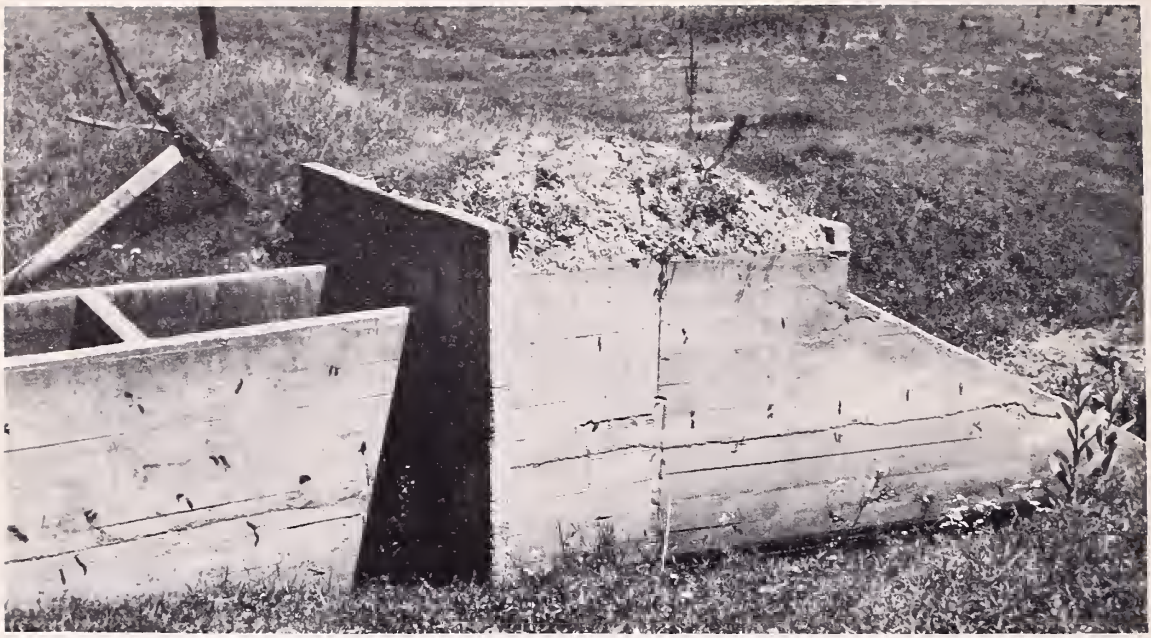

FIGURE 10.--Typical fill failure on box-inlet drop spillway resulting from combining a short antiseep collar with the headwall. Extending this collar farther into the fill probably would have prevented failure.

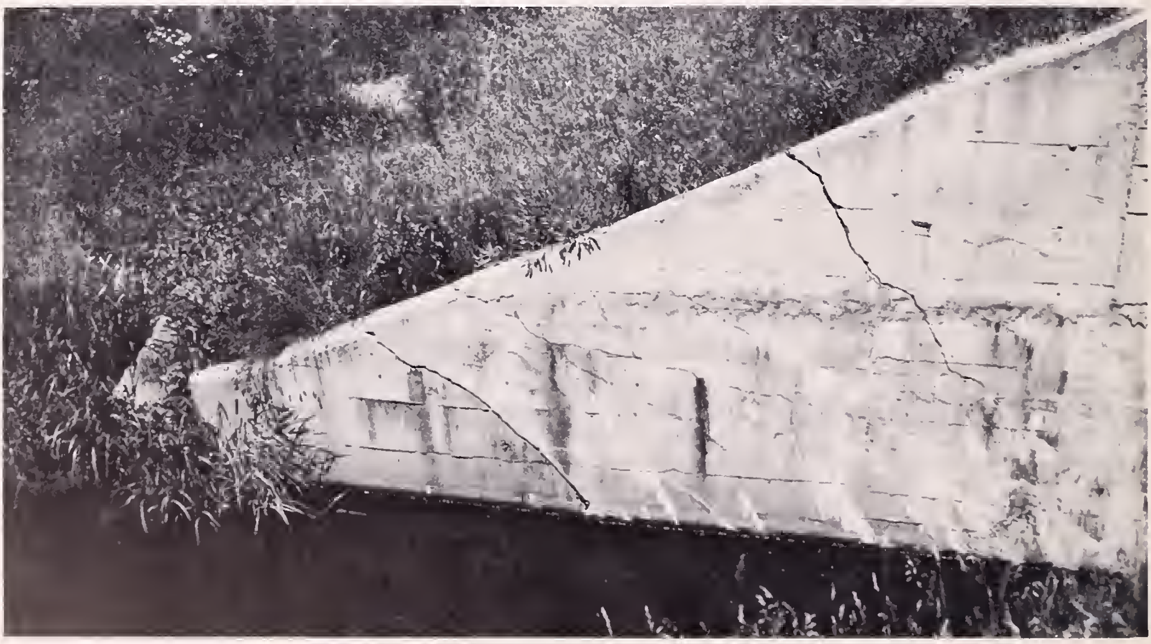

FIGURE 11.--Diagonal cracks on the outlet sidewall of box-inlet drop spillway due to improper structural design. This particular wingwall has also broken off.

12 illustrates a trapezoidal-type of inlet 30 feet long, 8 feet wide at the upstream end, and 15 feet wide at the headwall. The depth of the intake section was 10 feet but the upstream end was filled with rock covered with a 3-inch floor sloping up to 5 feet below the weir crest at the upstream end. Weighting this upstream end reduced the width of spread footing required to care for uplift.

Outlet conditions

Cutting below the outlet was not as serious with box-inlet structures as with drop-inlets, although the former type is generally designed to carry larger flows. Cutoffs in only five of the structures examined had been undermined. Two typical failures of this kind have been illustrated in an earlier publication.[5] Another of these structures which caused considerable erosion at the outlet had a foundation of almost pure sand and an excessively steep downstream gradient (fig. 13). Still another, located below a highway bridge, had a downstream gradient that was much too steep. Two were on a pure sand foundation requiring a specially designed outlet.

The other case of undermining (fig. 14) resulted from failure to take into account, in design, a drop of 3 to 4 feet a short distance downstream from the structure. The undermining, which occurred 2 years after completion of the structure, has remained essentially unchanged for the last 10 years, even though the largest floods, which were near design capacity, occurred in the past 5 years and the maximum tailwater was at the level of the outlet apron.

The structure with trapezoidal-inlet section shown in figure 12 was subjected to a flood with an estimated peak discharge of 1,400 cubic feet per second. The resulting erosion at the outlet is shown in figure 15. The maximum depth of the scour hole was about $2\frac{1}{2}$ feet at a distance of 30 feet downstream from the structure, but at the end of the apron the depth of scour was only 1 foot.

Although outlet erosion below the ordinary outlets of these structures has not been extremely serious, except on sand, the standard outlet design recommended for box-inlet drop spillway structures[6] provides greater assurance of permanency of installation and requires little, if any, more concrete. Even with this outlet, however, there may be considerable downstream scour of the channel bed after the sediment contributed by the advance of the gully has been eliminated.

Many of the structures were in need of some type of repair or maintenance (table 2). Periodic inspection and maintenance are essential.

Flumes or Chutes

The essential dimensions of the concrete flumes examined in this investigation are shown in figure 16. Table 3 gives a summary by counties of the number examined; the number, type, and reason for failures; and the maintenance or repair required. Only 3 of the 56 structures examined were complete failures. All of these were a result of undermining of the slope section. About one-third of the structures had some type of partial failure. Most of the partial failures were likewise due to undermining of the slope section. One-third of these structures need some type of maintenance.

Seepage conditions

In many of the early structures no provision was made for relief of seepage under the sloping section regardless of the length of this section. Any seepage developing under this section could travel the entire length of the chute and frequently would carry enough material with it to cause undermining. Where this condition was discovered early and the undermined area was filled with concrete grout under pressure, most structures have since operated quite satisfactorily. Failures may recur, however, since grouting does not correct the cause of the undermining. The most recent designs provide for tile drains and gravel filters around the inlet, along the sides of the outlet, and at intervals along the chute, usually above each construction joint. In some structures, however, the expansion or construction joints had opened up as much as 1 inch, indicating downslope movement of the lower section. In one instance, the roots of a small tree which had penetrated this joint will ultimately cause structural failure.

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[5] Donnelly, C. A. Design of an outlet for box inlet drop spillway. U. S. Dept. Agr. Soil Conser. Serv. SCS-TP-63, 31 pp., illus. 1947. [Processed.]

[6] See footnote 5.

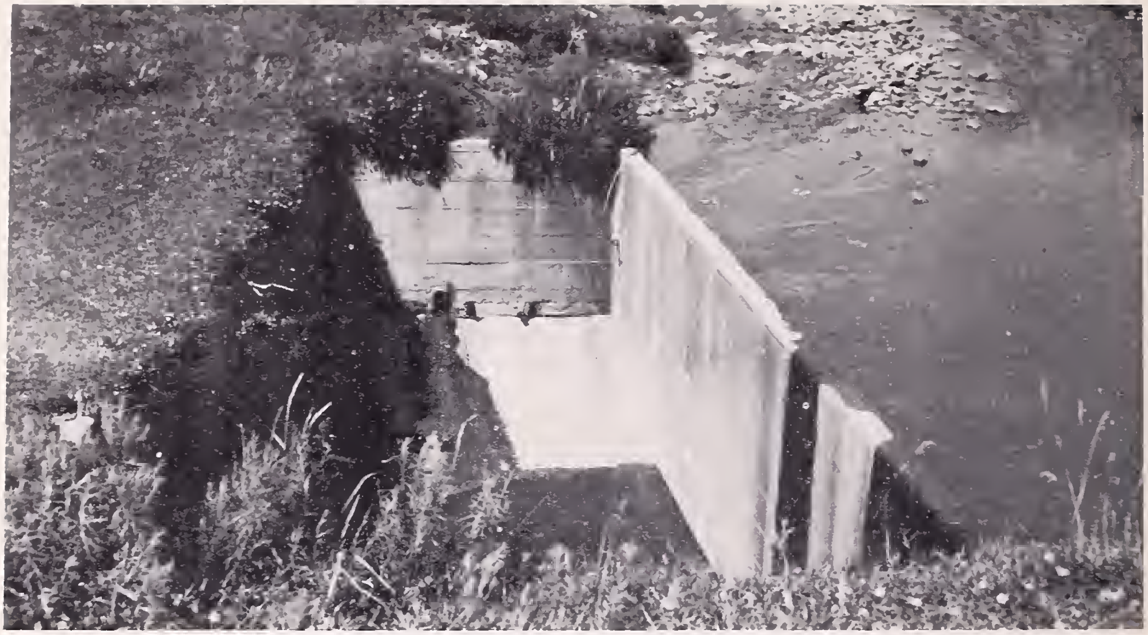

FIGURE 12.--Trapezoidal-inlet section on box-inlet drop spillway.

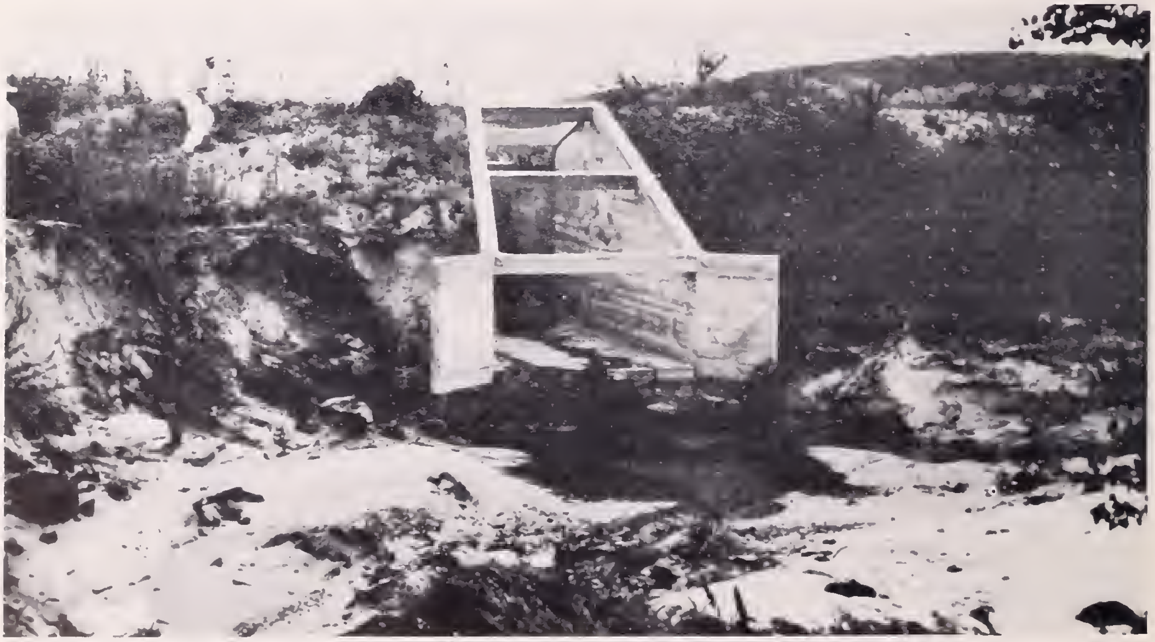

FIGURE 13.--Cutting at the outlet of box-inlet drop spillway on sand as the result of two near-capacity storms in 1934 shortly after completion of the job.

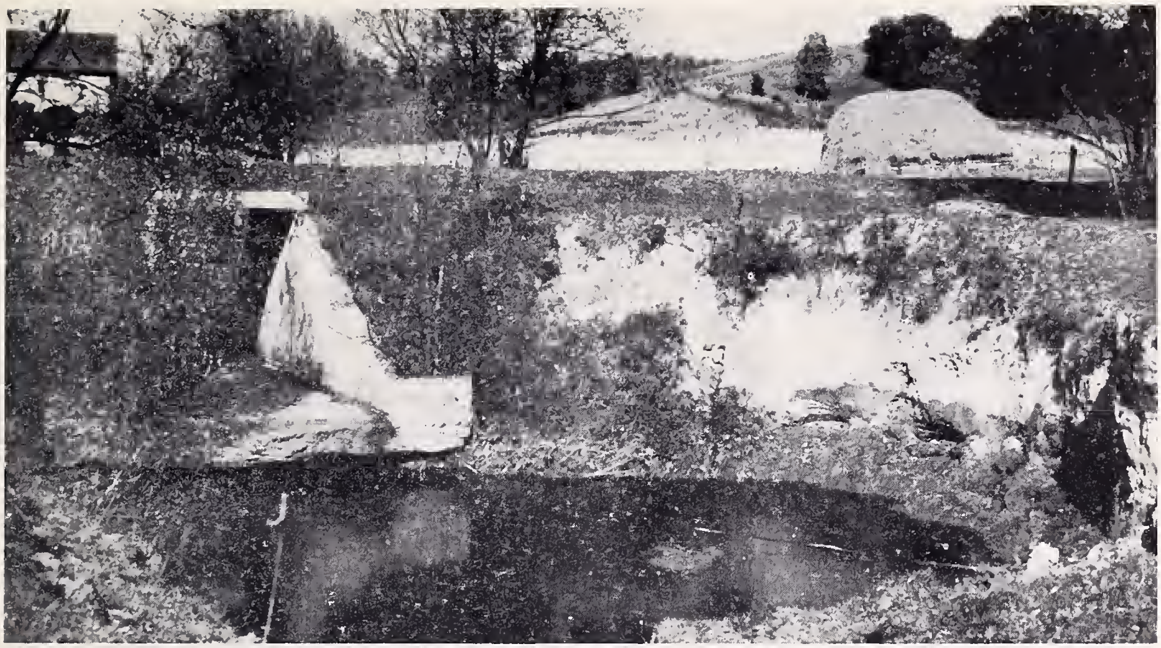

FIGURE 14.--Scour hole below box-inlet drop spillway in Trempealeau County. This condition has existed practically unchanged for the past 10 years even with several near-capacity flows and the maximum tailwater at the level of the apron.

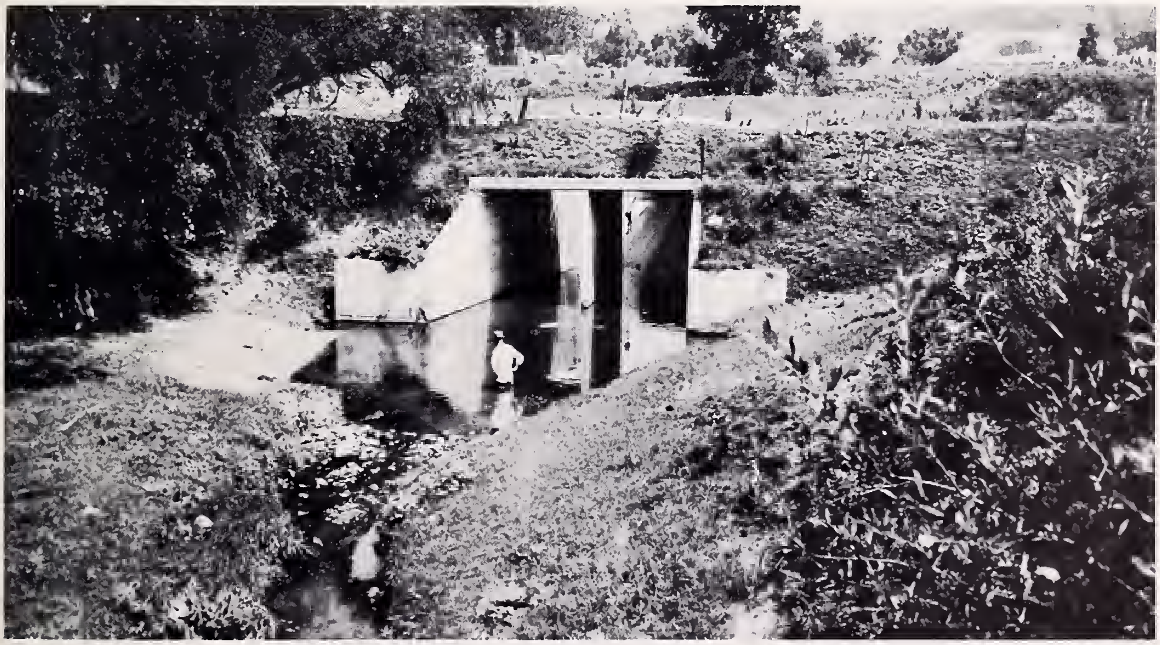

FIGURE 15.--Outlet conditions below a box-inlet drop spillway after the flood of July 27, 1949, with an estimated peak flow of 1,400 cubic feet per second. The white spot on the fill indicates maximum tailwater height. The maximum depth of scour hole was 2.5 feet. Original downstream gradient about 0.5 percent.

TABLE 3.--Flumes or chutes. Census of structure condition, failures, and type of remedial treatment required.

SITE AND STRUCTURE CONDITION

Description	County				Total
	Buffalo	Grant	La Crosse	Trempeleau	
	Number	*Number*	*Number*	*Number*	*Number*
Total examined	10	11	16	19	56
Complete failures	--	1	--	2	3
Partial failures	5	3	2	9	19
Structures needing repairs	--	--	1	1	2
Structures needing maintenance	4	2	4	10	20
Structures previously repaired	3	1	1	4	9
Structures having baffles or tumble-bay	1	0	3	3	7
Cutoffs undermined	1	1	0	1	3
Cutting at the outlet	2	4	3	8	17
Deposition at the outlet	1	--	2	1	4
Condition satisfactory	5	4	9	3	21
REASON FOR FAILURES					
Inlet cutoff undermined	--	3	--	2	5
Outlet cutoff undermined	1	--	1	4	6
Slope section undermined	1	2	1	4	8
Overtopping	--	--	--	2	2
Insufficient antiseep collars	--	--	1	1	2
Inadequate structural design	--	1	1	3	5
No aprom at bottom	1	--	--	--	1
Seepage	1	--	--	3	4
TYPE OF PARTIAL FAILURE					
Undermining	2	3	2	5	12
Break in fill	1	1	--	1	3
Break in construction joint	2	--	--	--	2
Cracks in sidewalls	3	1	1	4	9
Sloughing along sides	1	--	--	--	1
MAINTENANCE OR REPAIR REQUIRED					
Replace fill	1	1	--	2	4
Raise fill to design height	--	--	2	3	5
Repair cattle damage	1	1	1	2	5
Clear brush and weeds	1	1	1	1	4
Add antiseep collars	--	1	1	--	2
Add drop or SAF outlet	1	--	--	--	1
Extend cutoffs	1	2	1	2	6
Grout under chute	--	1	1	1	3
Repair construction joints	2	--	--	--	2
Remove silt above inlet or raise weir	--	--	--	1	1
Add toe drains	--	--	--	1	1

Outlet conditions

Since chutes or flumes are generally used at the heads of gullies where the channel gradient is steepest and there is little opportunity for storage, the structure must carry the natural undiminished flow from the watershed. In one-third of the chutes examined, cutting had occurred at the outlet, but only a few failures of this type of structure were due to this cause. The cutoff was undermined at only three structures. The results of the study indicate that for structures with a straight inlet and an outlet set reasonably deep, and where the head on the inlet is not more than 2 feet, no special design is necessary to prevent serious erosion. Where the chute is built with a box-inlet, which results in greater depths of flow, an improved outlet[7] should be used to insure permanency of the structure.

Many plans now being prepared require that the earth be piled more than halfway up on the sidewalls, apparently because this elevation is the approximate line of the original gully bottom or because such a fill is needed to conceal and protect toe drains. Where possible the slope of the fill should be extended to near the downstream end of the structure.

Livestock are doing considerable damage to low earth dikes. Frequent inspection and immediate and adequate maintenance are necessary to prevent such damage and prolong the useful life of this type of structure. Many extensive repair jobs would be avoided by simple maintenance work if the difficulty is discovered and corrected within a reasonable time.

Concrete Drop Spillway

Figure 17 shows the two most common types of drop spillway structure used in the early construction. The summary in table 4 shows the data by counties on the number of structures examined; the number, type, and reason for failures; and the number on which maintenance or repair is now required. As in the tabulations for other structures, this table lists more than one type of repair for individual structures. Thus, the structure in Grant County shown as needing repair requires both lengthening of the headwall extension and replacing of the fill.

Of the 32 structures examined, only 1 had failed completely, failure having occurred during the first year of operation. Failure was due to an extremely short apron and not enough downstream cutoff. In two other cases of undermined outlet, both in Buffalo County, the structures had been placed on almost pure sand and the downstream gradient was in excess of 2 percent (fig. 18), whereas the upper gradient limit for this type of material should be less than 1 percent. Partial failures (table 4) included the two instances of undermined cutoff mentioned above, and two fill failures which were probably caused by improper compaction of the fill and not enough length of headwall extension. Although drop outlets should be added to the two undermined outlets to prevent complete failure, the drainage area controlled by these structures is so sandy and of so little practical value for agriculture that great outlays for repair, in addition to the large expenditure already made, would not be justified.

Outlet conditions

Cutting at the outlet in general did not appear serious even though most of the structures of this type examined had no specially designed outlet. Only 12 of the 32 structures examined showed cutting, and 8 of these were in Grant County where the extent of damage was small due to the heavy soil. The design most commonly used at present, which is based on actual laboratory tests, requires one transverse and two longitudinal sills.[8] Although the structures examined do not conform to modern design requirements in this respect (fig. 18), their overall dimensions are approximately correct. Conformation with the latest designs will entail little additional expense and will provide a high degree of safety.

Most of the maintenance now required consists of raising or repairing cattle damage to earth fills. As with other structures, annual inspection and proper maintenance are essential if the structures are to continue to serve the purpose for which they were built.

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[7] Blaisdell, F. W. The SAF stilling basin. U. S. Dept. Agr. Soil Conserv. Serv. SCS-TP-79, 14 pp., illus. 1949 [Processed.]

[8] Morris, B. T., and Johnson, D. C. Hydraulic design of drop structures for gully control. Amer. Soc. Civil Engin. Trans. 108: 887-940. 1943.

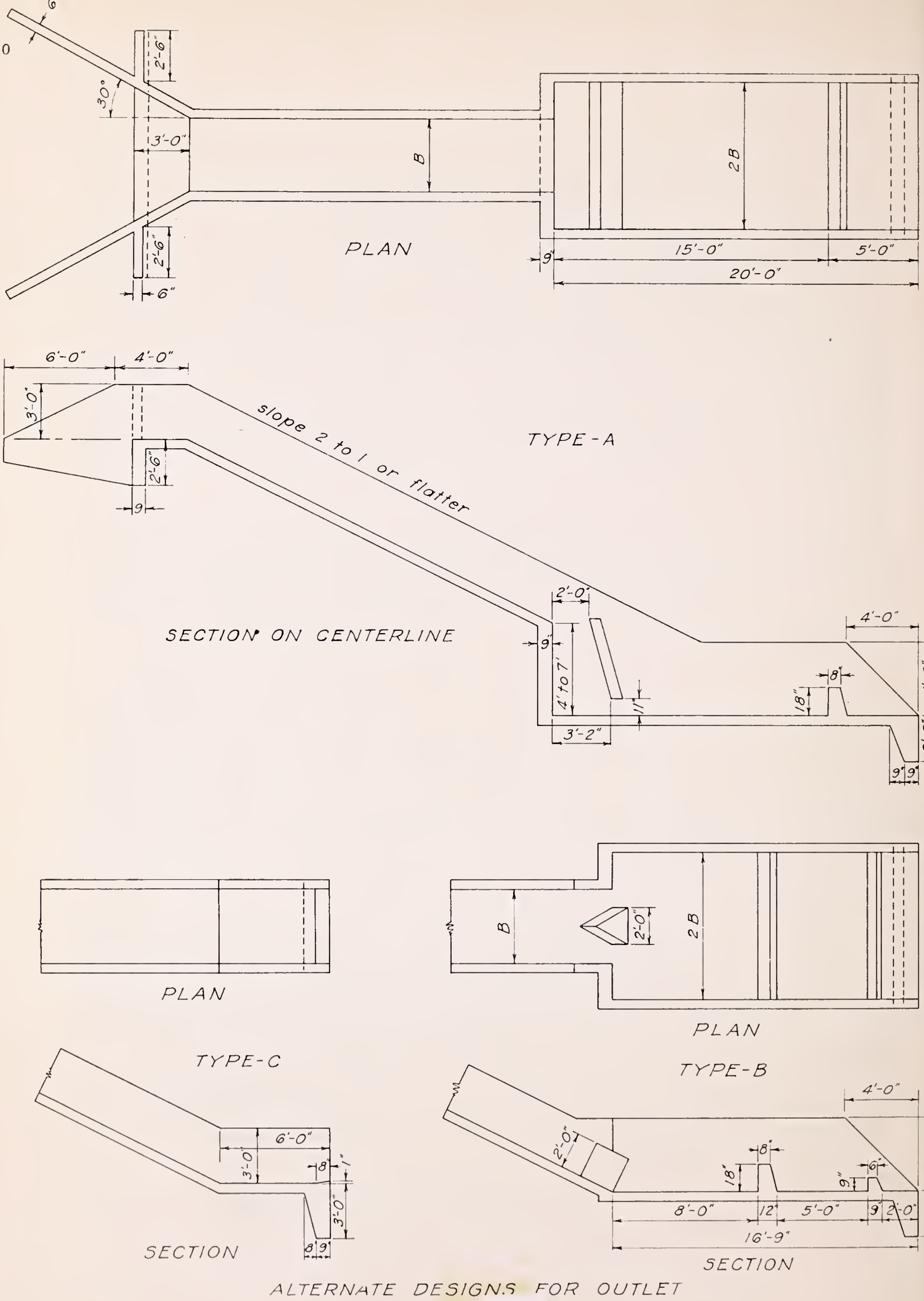

FIGURE 16.--Flumes or chutes: A, and B, Type with tumble-bay for reducing erosion at the outlet; C, type with plain outlet.

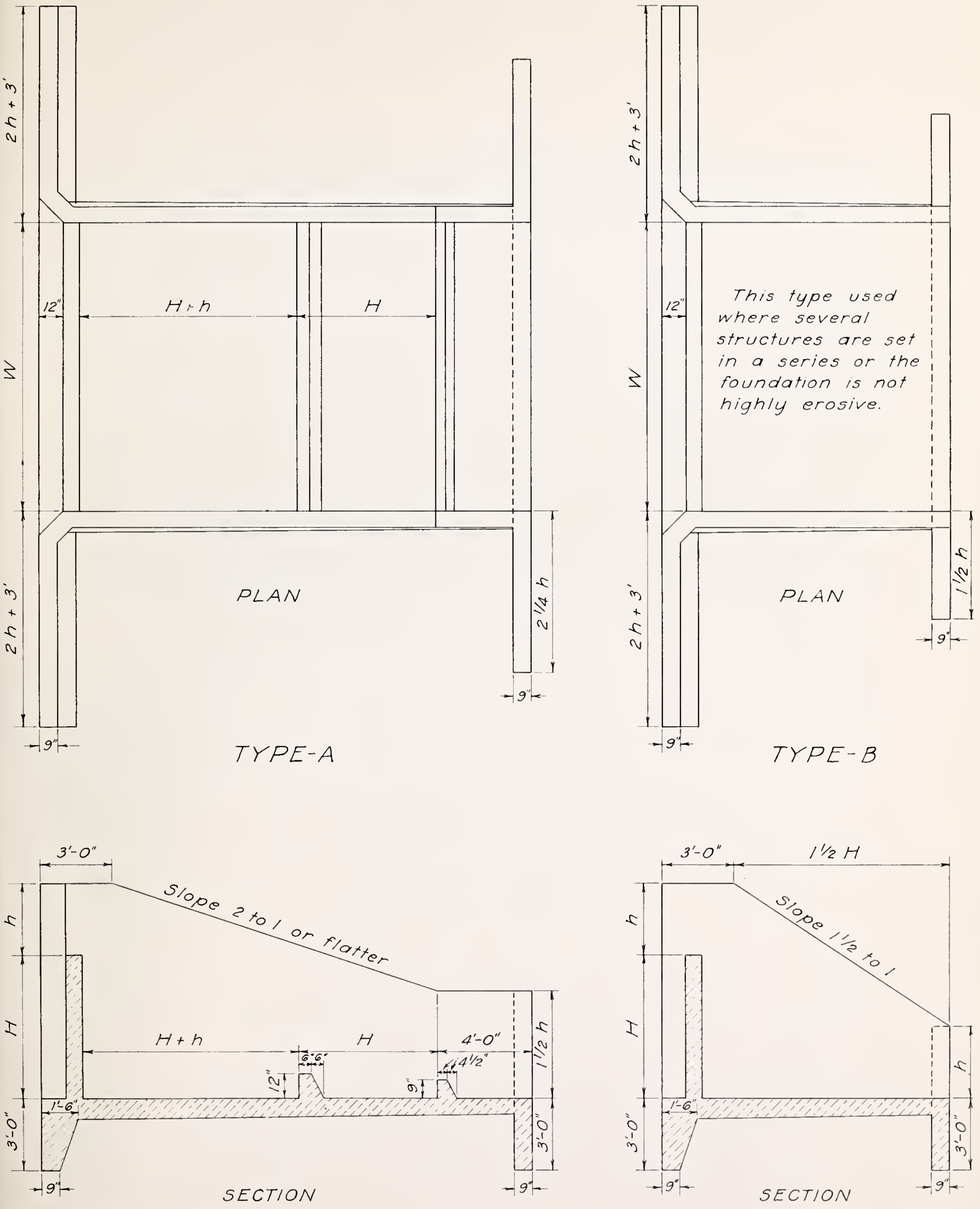

FIGURE 17.--Drop spillways: A, Type built on highly erosive soils; B, type built on nonerosive soils or as one of a series.

TABLE 4.--Concrete drop spillway (notch) structures. Census of structure condition, failures, and type of remedial treatment required.

Description	County				Total
	Buffalo	Grant	La Crosse	Trempeleau	
SITE AND STRUCTURE CONDITION					
	Number	*Number*	*Number*	*Number*	*Number*
Total examined	4	18	6	4	32
Complete failures	--	--	1	--	1
Partial failures	2	1	1	1	5
Structures needing repairs	2	1	--	--	3
Structures needing maintenance	1	8	1	2	12
Structures previously repaired	--	--	1	1	2
Structures with baffles or sills	2	--	--	1	3
Cutoffs undermined	2	--	1	--	3
Cutting at the outlet	2	8	1	1	12
Deposition at the outlet	--	4	--	--	4
Condition satisfactory	1	12	5	2	20
REASON FOR FAILURES					
Undermining	2	--	2	--	4
Insufficient cutoffs or collars	--	1	--	1	2
Overtopping	--	--	--	1	1
Inadequate structural design	--	--	1	--	1
Improper compaction of fill	--	1	--	--	1
Poor materials	--	--	--	--	--
Swirls around wingwalls	--	--	--	--	--
Too step downstream gradient	2	--	--	--	2
TYPE OF PARTIAL FAILURE					
Cutoff undermined	2	--	1	--	3
Break through fill	--	1	--	1	2
Antiseep collars undermined	--	1	--	1	2
Wingwalls broken off	--	--	--	--	--
Cracks in sidewalls	--	--	--	--	--
MAINTENANCE OR REPAIR REQUIRED					
Replace fill	--	1	--	--	1
Raise fill to design height	1	--	--	2	3
Repair cattle damage	1	4	--	--	5
Clear brush and weeds	1	2	1	--	4
Extend headwall extension	--	1	--	--	1
Extend cutoffs	--	--	--	--	--
Add drop outlet	2	--	--	--	2
Replace wingwalls	--	--	--	--	--
Remove silt from above inlet or raise weir	--	1	--	--	1

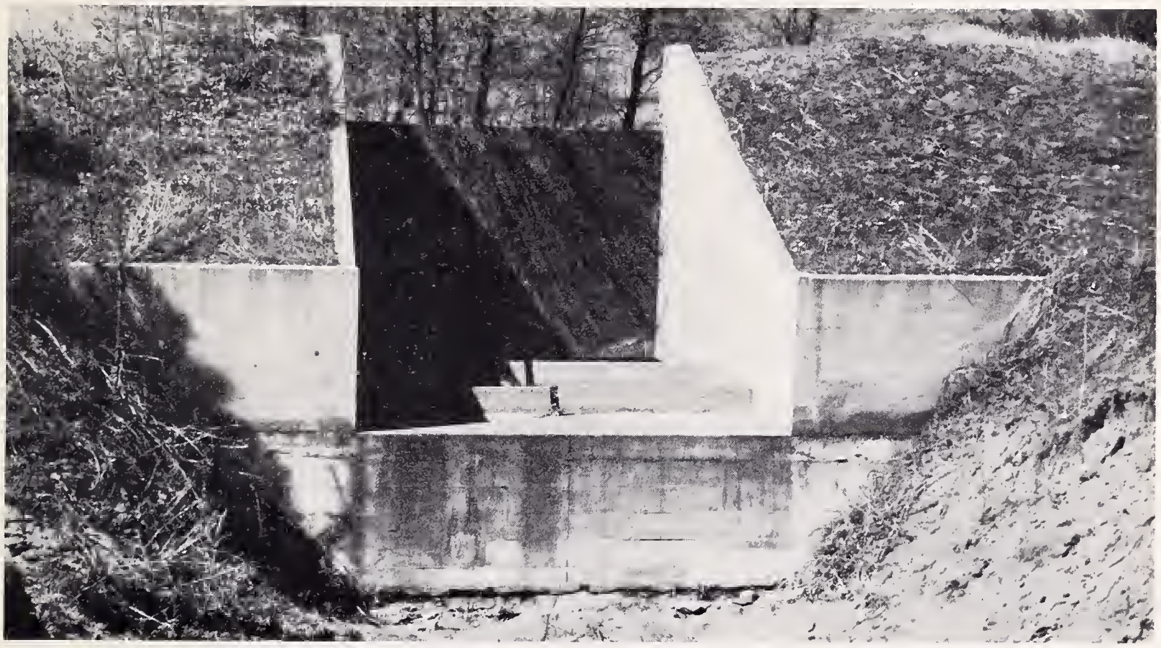

FIGURE 18.--Undermining of cutoff of drop spillway on sandy soil. Original downstream gradient 2 percent.

Masonry Drop Spillway

Only in Grant County was there any appreciable number of masonry structures. Over 20 percent of those examined were complete failures; an additional 20 percent were partial failures. Many of the remaining structures were in need of maintenance or repair. The tabulation (table 5) summarizes what was found in the examination.

Most of the failures were due to poor material or to not enough cutoffs or collars. All of these structures were built with locally quarried limestone rock.[9] The limestone, however, contained considerable sulphur and other impurities which made it unsuitable for either concrete aggregate or building stone. Much of it disintegrated rapidly under conditions of alternate freezing and thawing. It is extremely difficult to build good smooth cutoff walls or to satisfactorily compact the earth against masonry walls. Even if the proper material could be obtained and the necessary precautions taken, masonry would probably be more expensive than concrete construction.

Outlet conditions

Cutting at the outlet was not a serious problem, probably because the drainage areas generally were so small that the structures were required to carry only small flows. On many drainage areas of 20 acres or less, a sod waterway with concrete toe-wall would probably be cheaper than a masonry structure and equally satisfactory.

FURTHER STUDIES NEEDED

This study emphasized the need for further hydrologic data as a basis of adequate design. Rates and amounts of runoff have been measured on areas up to 330 acres near Fennimore, Wis., since 1938. Some additional information was obtained in the course of

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[9] The only limestone suitable for construction in Wisconsin is the Niagara limestone which is found in only a few places in southwestern Wisconsin.

TABLE 5.--Masonry drop spillway structures in Grant County Wis. Census of structure condition, failures, and type of remedial treatment required.

SITE AND STRUCTURE CONDITION

Description	Number
Total structures examined	32
Complete failures	7
Partial failures	7
Structures needing repairs	5
Structures needing maintenance	8
Structures previously repaired	1
Cutoffs undermined	0
Cutting at the outlet	1
Deposition at the outlet	0
Condition satisfactory	10
REASON FOR FAILURES	
Outlet undermined	--
Insufficient cutoffs and collars	8
Overtopping	--
Burrowing by animals and rodents	1
Poor compaction of fill	--
Poor material	9
TYPE OF PARTIAL FAILURE	
Cutoff undermined	2
Break through fill	3
Antiseep collars undermined	--
Disintegration of rock	11
MAINTENANCE OR REPAIR REQUIRED	
Replace fill	3
Raise fill to design height	3
Repair cattle damage	2
Clear brush and weeds	2
Lengthen headwall extension	2
Extend cutoffs	--
Add drop outlet	--
Remove silt from above inlet or raise weir	1
Place new top course or cap with concrete	5

this study by estimates based on high watermarks. These data, however, give only the maximum value experienced and no information on frequency of occurrence. About 20 sites were selected in the course of this study and these have already been equipped with maximum stage gages.

CONCLUSIONS AND RECOMMENDATIONS

1. Adequate and timely maintenance is the first requisite to insure continued satisfactory performance of structures.
2. Hydraulic design should be adequate and consistent with economy of construction. This does not mean, however, that all structures must be equipped with the latest approved type of outlet regardless of cost. Outlets for structures which are required to carry large quantities of water or to operate at maximum capacity for considerable periods of time, and outlets for structures located on highly erodible soils, should be designed to allow the least erosion under all flow conditions.
3. The building of permanent structures at sites where the watershed area is less than 20 acres is a questionable practice if soil and climatic conditions are suitable for the establishment of good sod. Under such conditions, sod flumes with concrete toe-walls are probably satisfactory and cheaper and can be built with farm labor and equipment commonly available.
4. Seepage at the toe of fills did not appear to be serious even though many of the fills were not provided with any form of toe drainage and the method of placement of fills in the early construction was given inadequate attention. Seepage caused by existing seeps and springs needs to be corrected by a properly designed drainage system.
5. Economy of materials makes it advisable to change the present shape of inlet on the box-inlet drop spillway.
6. Fifty percent of all structures examined were in satisfactory condition, and 35 percent more could be placed in good condition through ordinary maintenance. About 10 percent require extensive repairs to prevent ultimate failure.
7. Only a few of the structures were set sufficiently deep in the gully to provide any appreciable tailwater at the outlet during periods of peak discharge. Had they been set deeper, as specified in the more recent designs, outlet erosion would probably have been much less.
8. The information now available on sedimentation and maximum rates of runoff to be expected from watersheds of various sizes, shapes, slopes, and soil types is very inadequate for the proper design of gully-control and water-conservation structures. Much of the needed data can be obtained by means of simple study techniques and observations at selected locations. Numerous farms are available as sites of further studies.

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